Spring 5-2012

Transportation network analysis for bicycle suitability in Lincoln Nebraska using Geographic Information Systems (GIS)

Andrew J. Pedley
University of Nebraska-Lincoln

Transportation network analysis for bicycle suitability in Lincoln Nebraska using Geographic Information Systems (GIS)

By

Andrew J. Pedley

AN UNDERGRADUATE THESIS

Presented to the Faculty of

The Environmental Studies Program at the University of Nebraska-Lincoln

In Partial Fulfillment of Requirements

For the Degree of Bachelor of Science

Major: Environmental Studies

With the Emphasis of: Natural Resources

Minor: Biology

Under the Supervision of Robert D. Kuzelka, AICP

Lincoln, Nebraska

May, 2012

Table of Contents

Acknowledgements

Thank you to Bob Kuzelka, Emily Bordersen, Dave Gosselin and Sara Cooper for their guidance and academic support.

Thank you to Dave Carey from the Lincoln Planning Department, Dr. Yunwoo Nam from the University of Nebraska, Shane Dostel from Lincoln Public Works, and Rick Haden for consulting advice and help acquiring data.

Transportation network analysis for bicycle suitability in Lincoln Nebraska using Geographic Information Systems (GIS)

Andrew J. Pedley, B.S.

University of Nebraska, 2012

Advisor: Robert D. Kuzelka, AICP

Abstract

With increasing fuel costs, concern over global climate change, and increasing obesity levels, cycling is being promoted as a healthy sustainable alternative to automobile transportation. In order to improve a city's transportation network to accommodate cyclists, an assessment of the current system is needed. This project uses the Bicycle Compatibility Index (BCI) to rate the bikeability of streets in a subarea of Lincoln, Nebraska. In this study I assessed the feasibility of using the BCI rating method on a city-wide level and list suggestions to improve the method. The information created in this project can be used by planning officials to assess and enhance the area's suitability for bicycle commuting and, to create a useable bicycle commuter map.

Introduction

Transportation is a complex issue that plays a major role in the daily life of everyone. A well planned and organized transportation system is vitally important to the efficient movement of people and goods throughout a city. Deficiencies in the system can lead to traffic congestion and increased travel times. This study assesses the transportation network in Lincoln, Nebraska to identify streets that are most ideal for bicycle commuting. Using this information within a geographic information system (GIS) framework, a bicycle commuter map can be created.

In the United States, the automobile dominates the transportation landscape. By the end of World War II, most American families owned at least one car and had discovered the freedom of personal transportation. The automobile allowed Americans to build homes on the outskirts of cities and drive to work. As the number of autos increased, so did demand for automobile-specific infrastructure like freeways and parking lots. Currently, there are approximately 61,000 square miles of paved roads and parking lots in the US. This is an area slightly smaller than the state of Wisconsin (Heinen, Van Wee, & Maat, 2010).

Over the last 60 years, city planners and public administrators have been under pressure from both government and industry forces to focus solely on catering to automobile users while neglecting infrastructure for forms of transportation such as cycling and walking (Newman & Kenworthy, 1999). As a result, the automobile has been a major factor in the growth and design of American cities. Throughout the Twentieth Century, cities experienced rapid growth and there was very little importance placed on sustainability especially with regards to the transportation network. Therefore, it can be difficult for bicycle commuters to find safe and efficient bicycle routes using a transportation network designed for cars.

There are many practical benefits associated with automobiles. The sale and production of American autos plays an important role in the US economy. The automobile allows users to independently travel long distances. It is responsible for the creation of the US interstate highway system which transports people and goods across the country. Unfortunately, the overdependence on automobiles also carries with it many negative externalities. The most notable of these externalities are pollution, traffic congestion and suburban sprawl. Although the auto has been instrumental in the development and growth of our cities, “It is currently accepted by a growing number of planning scholars and practitioners that current trends in transportation are unsustainable” (Balsas, 2002).

A main cause of our overdependence on automobiles is the artificially low cost of ownership. This is the result of subsidies, regulations, developments in technology, and planning efforts that have favored auto users. The availability of inexpensive fuel, few and low cost toll roads, and large amounts of free parking are some of the factors that reduce the cost of autos while increasing their externalities. The over reliance on auto use has not only reduced transportation diversity (Gardner, 1998), it has led to many problems with the environment, public health and land-use. The overuse of autos has been linked to the degradation of the natural environment through air and water pollution, and the loss and fragmentation of rural lands and wildlife habitats. It has depleted natural resources and has isolated users from social interactions experienced in dense walkable and bike-able environments (Newman & Kenworthy, 1999). Cycling or walking instead of driving can offer physical activity that can help to combat the rise in obesity and cardiovascular disease in the United States as well (Killingsworth, De Nazelle, & Bell, 2003; Moudon & Lee, 2003). However, until there is a shift in policies and practices to take into account the full cost of automobile usage, few incentives exists for a change in mode choice (Wilkinson, 1998).

There are many reasons to encourage individuals to commute by bicycle instead of automobile. Cycling is a healthy and inexpensive form of transportation and in dense urban areas, it can even be faster to bike than drive because cyclists are able to avoid traffic jams and do not need to search for parking. For society, cycling has the advantage of environmental sustainability, it requires less infrastructure and can lead to improvements in public health (Heinen, Van Wee, & Maat, 2010). Cycling does however have its limitations. It can be difficult to carry loads by bike and cyclists are susceptible to changes in weather. Cycling is generally slower outside of dense urban areas and longer distances can be limiting as well. (Allen-Munley & Daniel, 2006)

The United States Department of Transportation has stated goals to double the number of trips made by bicycling or walking and to simultaneously reduce the number of pedestrian and bicyclist injuries and fatalities by 10 percent (Federal Highway Administration, 1994). In order to accomplish that goal, stakeholders must begin by understanding and evaluating the current roadways to identify which streets are most user-friendly from the perspective of the bicyclist. Therefore, the primary objective of this study is to use the Bicycle Compatibility Index (BCI) formula within a GIS framework to rate the streets in a subset of Lincoln, NE. The second objective is to determine the feasibility of implementing this method to the entire city. The project's final objective is to identify ways that the information created in this project can be used to create a reliable and useful bicycle commuter map.

Literature Review

Due to the relative vulnerability of a cyclist in traffic, safety is commonly listed as a primary concern of commuter cyclists. Parkin et al. (2007) list 'unpleasantness of traffic' and 'poor motor vehicle driver behavior' as barriers to cycling. Other deterrents identified are 'aggressive driver behavior' and 'personal security fears' (Davies et al., 1997). By choosing routes that use streets more suited to accommodate both cars and bicycles, many of these concerns can be avoided.

After searching the literature and interviewing professionals in the planning field, I identified potential methods for quantifying the bikeability of the transportation network. The two most used of these formulas are the Bicycle Compatibility Index and the Bicycle Level of Service (BLOS) index. The third formula that I identified was used to rank Lincoln's streets while planning the city's on-street bike routes.

The first method that I investigated is FHWA's Bicycle Compatibility Index (BCI) (Harkey et al., 1998).

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

BL= Presence of a bicycle lane or paved shoulder ≥.9m wide. no=0, yes=1
BLW= Width of bicycle lane (Meters).
CLW= Curb lane width (Meters).
CLV= Curb lane traffic volume per hour.
OLV= Other lane (same direction) traffic volume per hour.
SPD= 85^{th} percentile speed of traffic (km per hour).
AREA= Type of roadside development. residential=1, other=0
PKG= Presence of parking lane with over 30% occupancy. no=0, yes=1
AF= Additional adjustment factors including right turn frequency, percentage heavy vehicles and parking turnover rate.

The BCI method was developed using surveys. In order to be able to accurately weight the importance of specific features of the built environment, the developers of this method showed study participants video of mid block street segments. The participants were then asked to rate their level of comfort with each video. The researchers then analyzed the responses based on the measurements and conditions of the streets to develop the rating formula (Harkey et al., 1998).

The second method that I investigated was the Bicycle Level of Service (BLOS) formula (Landis, Battikuti, & Brannick, 1997).

$$\mathrm{BLOS} = 0.507\ln(\mathrm{vol}_{15}/\mathrm{Ln}) + 0.199\mathrm{SP}_t(1 + 10.38\mathrm{HV})^2 + 7.066(1/\mathrm{PR}_5)^2 - 0.005\mathrm{W}_e^2 + 0.760$$

Vol_{15} = Volume of directional traffic in 15 minutes.
Ln = Number of directional through lanes.
SP_t = Posted speed limit.
HV = Percent heavy vehicles.
PR_5 = The Federal Highway Administration (FHWA) 5 point pavement rating. (1 is the worst, 5 is the best)
W_e =Width of the outside through lane.

This index was developed in a similar way to the BCI but unlike BCI, BLOS was developed using on-bike perceptions as opposed a video survey. Like the BCI, the BLOS index calculates a level of service rating based on the built environment and usage of the street. BLOS formula is regarded by many as the best formula for assessing level of service because it addresses traffic volume logarithmically, which more accurately depicts real human perceptions.

The final method that I considered for this project was developed specifically to rate Lincoln's streets for its first bicycle assessment in 1977 (Mayor's Bicycle Safety Committe, City of Lincoln, Nebraska, 1977).

Street Index= (V/10W) (S) (9C) (U)

V= Car volume + 3(truck volume) in peak one hour period
W= Travel width of roadway, subtracting 8 feet for each parking lane (1/2 of divided roadway)
S= Speed limit of street
Condition of pavement, gutters, and inlets for bicycle use
  Good=1.00
  Fair=1.25
  Poor=1.50 (gravel road, brick surface or grates parallel to direction of travel)
U= Unusual condition 1.00+
  0.10 Parking on 50% of block side
  0.10 3-lane roadway
  0.20 4-lane roadway
  0.10 Each slope over 400ft distance with >4% grade
  0.10 Per arterial crossing without controls
  0.10 Mandatory turn lane

Like the BLOS index, this rating system requires pavement condition and heavy vehicle data. It also focuses heavily on parking in the formulation of the index. When this formula was used, a group of volunteers collected data in the field instead of using preexisting GIS datasets. The information created from the implementation of this formula was used to develop Lincoln's first on-street bike route system.

Of the three methods identified, I chose to use the BCI for this project. BCI is a currently used method and the data that I was able to obtain fit it best. I would have preferred to use the BLOS model because it better represents traffic volume perceptions but I was unable to obtain heavy vehicle percentages and FHWA pavement quality data. I chose not to use the Lincoln street index rating system because it also required heavy vehicle percentages and FHWA pavement quality data. It was also the most dated of the three methods investigated.

Materials and Methods

The methodology used for this project follows FHWA's Bicycle Compatibility Index (BCI) implementation manual (Federal Highway Administration, 1998). The BCI (Figure 1) is a formula that assesses how well suited a street is for bicycles based on the characteristics of that street. It was developed in 1998 to be used by state and local planners and engineers to help improve the design and function of bicycle infrastructure in the existing streetscape.

Figure 1. The BCI formula (Harkey et al., 1998).

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

BL= Presence of a bicycle lane or paved shoulder ≥.9m wide. no=0, yes=1
BLW= Width of bicycle lane (Meters).
CLW= Curb lane width (Meters).
CLV= Curb lane traffic volume per hour.
OLV= Other lane (same direction) traffic volume per hour.
SPD= 85^{th} percentile speed of traffic (km per hour).
AREA= Type of roadside development. residential=1, other=0
PKG= Presence of parking lane with over 30% occupancy. no=0, yes=1
AF= Additional adjustment factors including right turn frequency, percentage heavy vehicles and parking turnover rate.

Since one of my objectives for this project was to determine if this method could be implemented on a city wide level, I needed to first choose an acceptable subset of Lincoln, NE for my study area. My starting map of Lincoln contained over 17,000 street segments. In order to make the project manageable I needed to narrow that down to around 3000 street segments.

The area of study for my project is midtown Lincoln, Nebraska. The study area is bounded on the north side by Cornhusker Highway and by Van Dorn Street on the south side, 48^{th} street and 1^{st} street make up the east and west boundaries respectively. I decided to use this area of Lincoln because it includes both City and East campuses of the University of Nebraska as well as downtown Lincoln and many residential areas with mixed density. The streets in the study area are mostly laid out in a grid pattern and many share similar environmental features such as lane width, and speed limit.

To calculate BCI for all streets in my study area, I needed to start with an existing geospatial database and then build a data set to satisfy the variables of the BCI formula. I used the Lancaster County streets centerline shape file to create the base map for my project (City of Lincoln Public Works, 2012). This map contains the name, location, and speed limit for each street segment in Lancaster County. Using ArcMap, I created a sub set consisting of 3329 street segments, from the county-wide map to show only my study area. The map and attribute table from this subset provided the foundation for my entire data set.

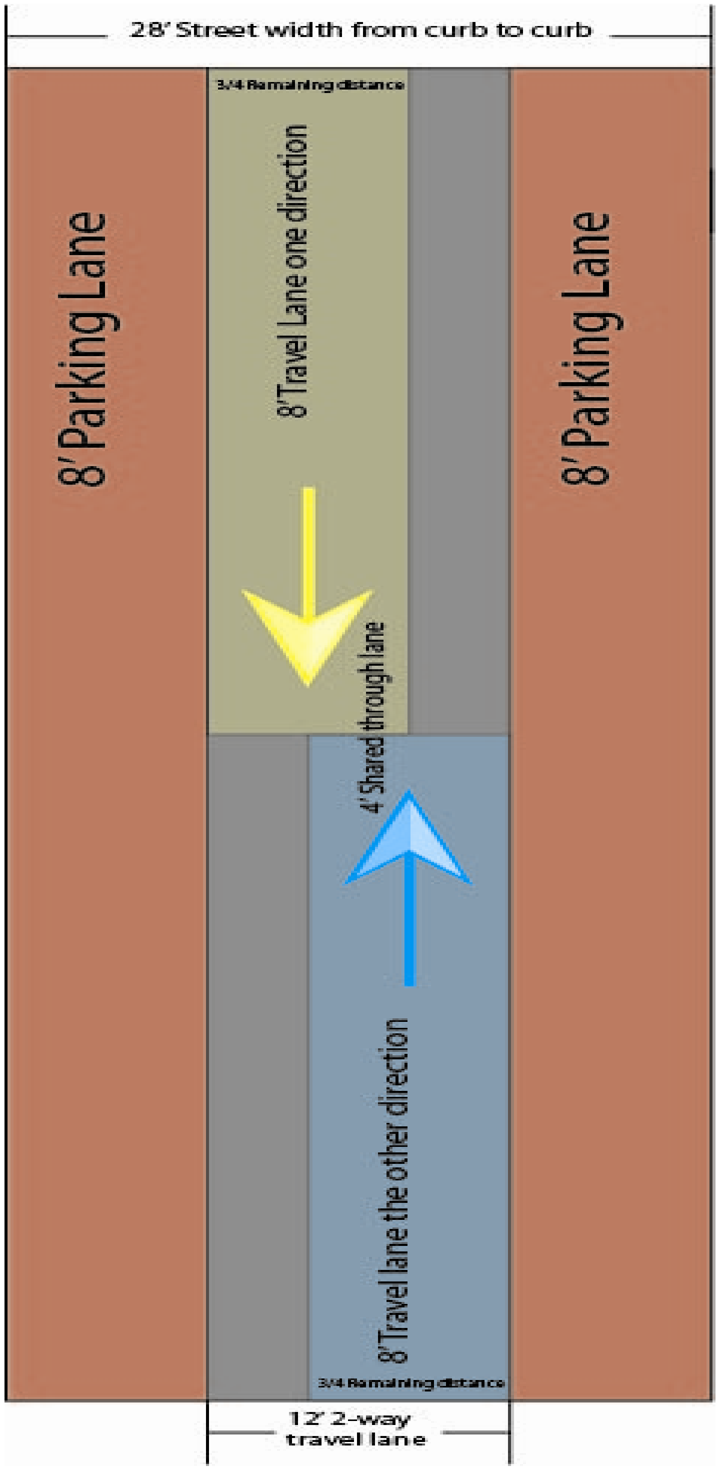
In order to use the map with the BCI formula, I needed to add variables to my data set in ArcMap. The first variable that needed to be entered into the data set was curb lane width (CLW). Since I was unable to obtain a GIS compatible map that included lane width data, I had to gather this information manually. I downloaded AutoCAD files from the Lincoln's Public Works ftp site (City of Lincoln Public Works, 2012). Those files provided a blueprint of the physical dimensions of the streets as well as all painted street markings. With these files, I used measurement tools in AutoCAD to manually measure the width of all painted lanes in my study area as well as the total width of all streets without painted lines. I also used these files to identify and document multiple-lane street segments as well as the presence of bicycle lanes (BL) and Bicycle Lane Width (BLW).

The next step in the data processing for the CLW variable was to calculate the lane width of all unpainted streets. These streets, primarily residential in nature, required me to make some blanket assumptions. Because I was unable to obtain on-street parking data, I made the assumption that all streets without marked lanes had parking on both sides of the street and shared the main through lane with on-coming traffic. In order to calculate lane width in this circumstance, I assumed that each street segment had an 8ft parking lane going in each direction and used ¾ of the remaining distance as the travel lane. The ¾ travel lane calculation represents the portion of the street that a car normally occupies on this type of street. For example if a residential street was 28ft wide, 16ft was subtracted to account for parking and ¾ of the remaining 12ft accounted for the directional curb lane width of 8ft (Figure 2).

Figure 2. Lane width calculation for residential streets.

CLV= 3/4(SW-16)

SW= Street Width



The next variables that I entered and processed were Curb Lane Volume (CLV) and Other Lane Volume (OLV). I obtained Average Daily Traffic (ADT) volume data from the Lincoln Planning Department (City of Lincoln Planning Department, 2012). ADT data is compiled from traffic cameras at all intersections that have traffic lights. As a result, this data set is incomplete because it does not include ADT figures for residential streets. Speaking with representatives from the Lincoln Public Works office, I was informed that an acceptable estimate of residential traffic volume is 500 vehicles per day (Dostel, 2011).

The BCI formula requires traffic volume data for CLV and OLV as per hour, directional traffic volume. The source data that I had was for average daily traffic in both directions. To convert my data from ADT to per hour directional values, I divided the ADT by the total number of through lanes both in both directions to get the daily per lane volume. Then I divided the daily per lane value by 24 to get hourly volume. These data were then entered into my final data set. I also made the assumption that in the presence of multiple lanes, CLV and OLV were equal and that for single lane streets OLV= 0 (Figure 3).

Figure 3. In order to include traffic volume in the BCI formula, ATD needed to be converted to CLV using the following formula.

$$CLV=ADT/24L$$

CLV= Curb lane traffic volume per hour
ADT= Average daily traffic volume
L=Total number of through lanes

To satisfy the land use variable of the formula (AREA) I used the county land use GIS map to identify residential streets (City of Lincoln Public Works, 2012). I used the spatial selection tool in ArcMap to select all streets that were located within urban residential areas on the county land use map. The streets selected were then given a value of 1 and those not selected were assigned a 0.

I was unable to find reliable data regarding parking occupancy (PKG), percentage heavy vehicles, right turn frequency and parking turnover (AF). As a result, I needed to make the assumption for all streets that these values were 0, in essence eliminating these variables from the equation.

Once I finished building my data set, I calculated BCI score for every street segment in my study area using Microsoft Excel. Then I joined my final BCI data table to my base map using the join tool in ArcMap. I then created a color coded map of my study area based on each street's BCI rating.

Results

Within a GIS framework, I rated all 3329 street segments in my study area using the FHWA's Bicycle Compatibility Index. I then created a map and color coded each street segment based on its BCI ranking A to F (Appendix A) Of the 3329 individual street segments in the study area, .04% rated in the A category (BCI≤1.5), 3.2% rated in the B category (1.51≤BCI≤2.3), 73.9% rated in the C category (2.31≤BCI≤3.3), 22.0% rated in the D category (3.31≤BCI≤4.3), 0.5% rated in the E category (4.31≤BCI≤5.3), and 0.0% rated in the F category (BCI≥5.31) (Figure 4).

Figure 4. This table shows the rating system for BCI and the percentage of the study area that received each rank.

Level of Service	Compatibility Level	BCI Range	Percentage of Study Area
A	Extremely High	BCI≤1.5	.04%
B	Very High	1.51≤BCI≤2.3	3.2%
C	Moderately High	2.31≤BCI≤3.3	73.9%
D	Moderately Low	3.31≤BCI≤4.3	22.0%
E	Very Low	4.31≤BCI≤5.3	0.5%
F	Extremely Low	BCI≥5.31	0.0%

Discussion

The first objective of this project was to rate all of the streets in my study area using the BCI formula in a GIS framework. Appendix A shows location and rating of these streets. The BCI implementation manual (Federal Highway Administration, 1998) suggests that all streets with a C or better rating offer a moderately high comfort level for casual cyclists. In my study area 77.1% of Lincoln streets rank C or better meaning that most streets in Lincoln are equipped to accommodate both motorists and bicyclists.

The results of my BCI calculations were generally what I expected. Arterial and collector streets like “O” Street, Antelope Valley, “K” Street and “L” Street were ranked D or lower. This was expected due to the relatively high speed limits and traffic volumes of these streets. Likewise, most residential streets were ranked C or better. The BCI model also identified wide, low speed streets with low traffic volume as exceptionally bicycle friendly. Streets like 11th Street, Goodhue Blvd. and “F” Street all are rated B or better-(Figures 5-6).

Figure 5. Downtown Lincoln

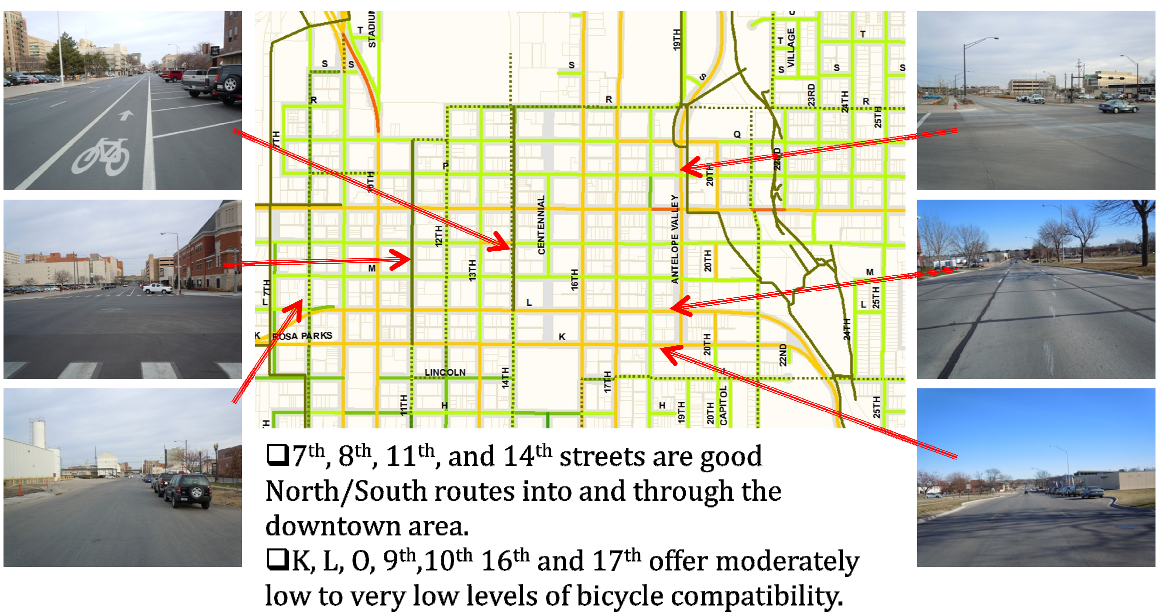
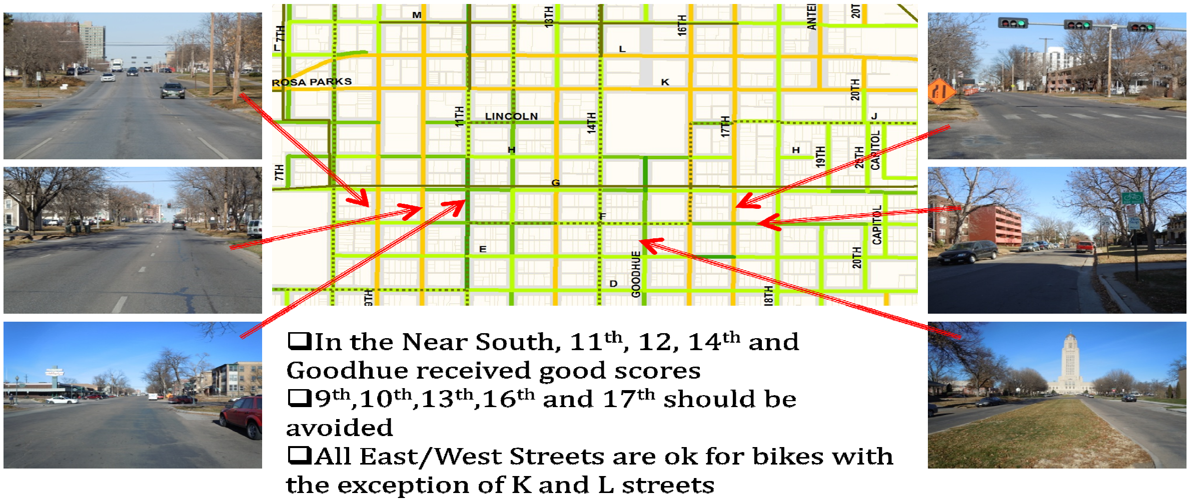


Figure 6. Near South neighborhood Lincoln



I was surprised to see that some of the on-street bike routes in Lincoln existed on streets that received poor BCI ratings. Figure 7 shows portions of 44th and "R" Streets that are designated bike routes but may offer less than ideal levels of serviceability. This is likely because although these streets are wide, they have a relatively fast speed limit and service a heavy volume of automobiles. I would suggest that the City of Lincoln take a closer look at the conditions of these streets and attempt to make changes that could lower the BCI score.

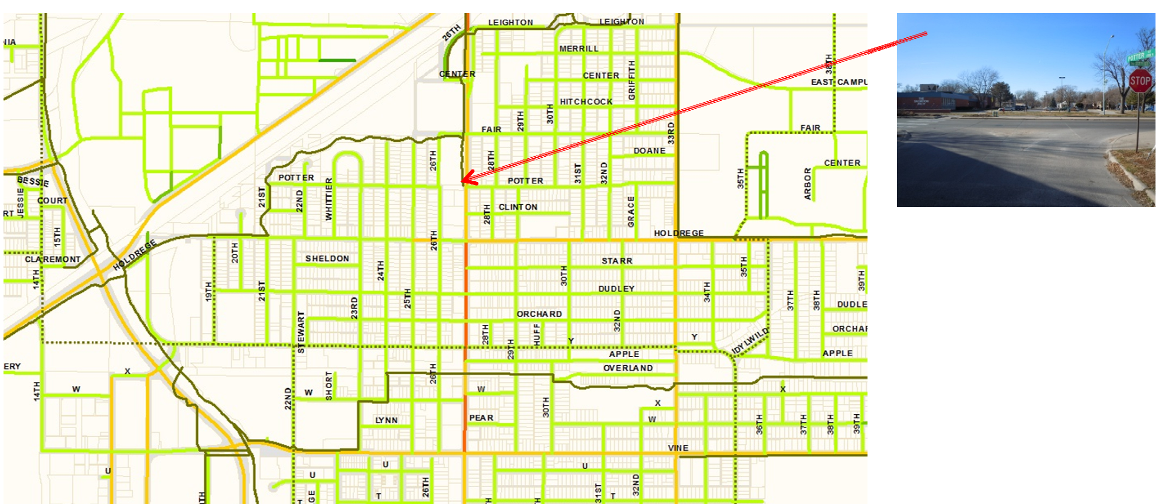
Figure 7. Midtown Lincoln

❑R street connecting 48th and 44th is designated by Lincoln as an on street bike route but gets D BCI rating.
❑Both 35th ad R (West of 35th) get a C rating and are acceptable bike friendly streets.

My second objective for this project was to determine if the BCI can effectively be implemented in a GIS framework. Judging from the results in my study area, it appears that this method can be used accurately calculate the bikeability of streets. There are limitations however. In order to complete my data set, several assumptions and omissions had to be made. To obtain more accurate ratings, these assumptions should be reduced. Another issue that could limit the city wide implementation of this method is the large amount of information needed to be processed. Manually measuring and entering lane width and traffic volume data is extremely time consuming.

This method is also limited because it only assesses the level of service of street segments and ignores intersections. Due to an increase in turning cars and cross traffic, an intersection can be the most dangerous part of a roadway for a cyclist. This method does not address intersection serviceability at all. This method also cannot be used to identify streets that effectively cross major arterials. Many of Lincoln's arterial streets have curbed medians that in some places may not allow bicycles or pedestrians to cross. Locating pedestrian cutaways in these medians like the one in figure 8 will help in identifying efficient routes.

Figure 8. Pedestrian and bicycle friendly curb cutaways.



Potter Street is an acceptable route between city and east UNL campuses. The map shows a gap in the street at 27th street when in actuality a pedestrian cutaway allows for easy crossing.

My third objective was to identify ways that this information can be used to create a useful bicycle commuter map. The most important step to use this model to create a commuter map is to eliminate as many of the assumptions and omissions as possible. By generating a parking dataset that included the presence of on street parking and parking turnover, I would be able more accurately calculate CLW and OLW and include PKG and AF data.

In addition to improving the accuracy of the data set, I think it could be important to take a closer look at the connectivity of each street as a whole. The BCI method currently looks only at individual street segments (the space from one intersection to the next). A more useful map can be created by identifying the streets with more intersections that travel longer distances. By focusing on connected streets users will be less likely to end up at dead ends or need to backtrack due to T-intersections. By emphasizing highly connected streets and by improving the accuracy of the data set, a useful and reliable bicycle commuter map can surely be created using information gained from this project. It can then be used to help commuter bicyclists find safe effective routs within the city.

Summary and Conclusions

An important step in creating a transportation network that accommodates all users is evaluate the existing network and determine what areas are considered bicycle friendly and what areas need improvement. This project used the BCI rating formula in a GIS framework to rate the streets in Lincoln, Nebraska. It also examined the feasibility of using the BCI rating formula to evaluate the existing road network and provides insight into potential improvements to my methods.

The map created in this study shows that this BCI method can be used to rate the streets of Lincoln. The data show that the majority of streets in the study area offer at least a moderately high level of comfort for the casual cyclist. While the method used provided fairly predictable results, if parking and ADT data existed fewer assumptions would have to be made and results could be more accurate. In addition to creating a more accurate data set, future studies should investigate connectivity of street segments to provide users with more efficient route choices.

We are currently at a point in time where we are starting to realize that our current transportation system is unsustainable. By including walking and biking as well as public transportation, we can reduce the strain that our current auto-centric society is putting on our environment, public health and transportation network. This type of network assessment can be used by planners and engineers to make policy and design decisions. It can also be used by commuter cyclists to aid in route choice. By helping to increase bicycle and walking as a form of transportation, this type of study can help to solve the current environmental and social problems that have arisen from the last 70 years of transportation policy.

Works Cited

Allen-Munley, C. P., & Daniel, J. (2006). Urban bicycle route safety rating model application in Jersey City, New Jersey. *Jorunal of transprotation engineering*, 499-507.

Balsas, C. J. (2002). New direction for bicycle and pedestrian planning education in the US. *Planning Practice & Research, 17*(1), 91-105.

City of Lincoln Planning Department. (2012). *City of Lincoln and Lancaster County geographic information systems map shop*. Retrieved from City of Lincoln and Lancaster County Planning Department web site: http://www.lincoln.ne.gov/city/plan/gisweb/home.htm

City of Lincoln Public Works. (2012). *Lincoln GIS ftp site*. Retrieved December 2012, from ftp://gisftp.lincol.ne.gov/download/gis/

Davies et al. (1997). Attitudes to cycling: a qualitative study and conceptual framework. *Transport Research Laboratory, 266*.

Dostel, S. (2011, November 12). (A. Pedley, Interviewer)

Federal Highway Administration. (1994). The National Bicycling and Walking Study. *FHWA-PD-94-023*.

Federal Highway Administration. (1998). *The bicycle compatibility index: A level of service concept, implementation manual.* FHWA-RD-98-095.

Gardner, G. (1998). When cities take bicyles seriously. *World Watch, 11*(5), 16-19.

Harkey et al. (1998). Devleopment of the bicycle compatibility index: a level of service concept. *FHWA-RD-98-072*.

Heinen, E., Van Wee, B., & Maat, K. (2010). Commuting by bicycle: An overview of the Literature. *Transport Reviews, 30*(1), 59-96.

Killingsworth, R., De Nazelle, A., & Bell, R. (2003). Building a new paradigm: Improving public health through transportation. *Institute of Transprotation Engineers ITE Journal, 73*(6), 28-32.

Krizek, K. J., Barnes, G., & Thompson, K. (2009). Analyzing the Effect of Bicycle Facilities on Commute Mode Share over Time. *Journal of urban planning and development, 135*(2), 66-73.

Krizek, K. J., Poindexter, G., Barnes, G., & Mogush, P. (2007). Analysing the Benefits and Costs of Bicycle Facilities via Online Guidlines. *Planning, Practice & Research, 22*(2), 197-213.

Landis, B. W., Battikuti, ,. V., & Brannick, M. T. (1997). Real-time human perceptions: toward a bicycle level of service. *Transportation Research Record*, 119-126.

Mayor's Bicycle Safety Committe, City of Lincoln, Nebraska. (1977). *Bicycles in the Community: Response and results.* Lincoln, Nebraska.

Moudon, A. V., & Lee, C. (2003). Walking and bicycling: An evaluation of environmental ausit instruments. *American Journal of Health Promotion, 18*(1), 21-37.

Newman, P., & Kenworthy, J. (1999). *Sustainability and cities: Overcoming automobile dependence.* Island Press.

Parkin, J., Wardman, M., & Page, M. (2007). Models of preceived cycling risk and route acceptability. *Accitent Analysis &Prevention, 39*, 364-371.

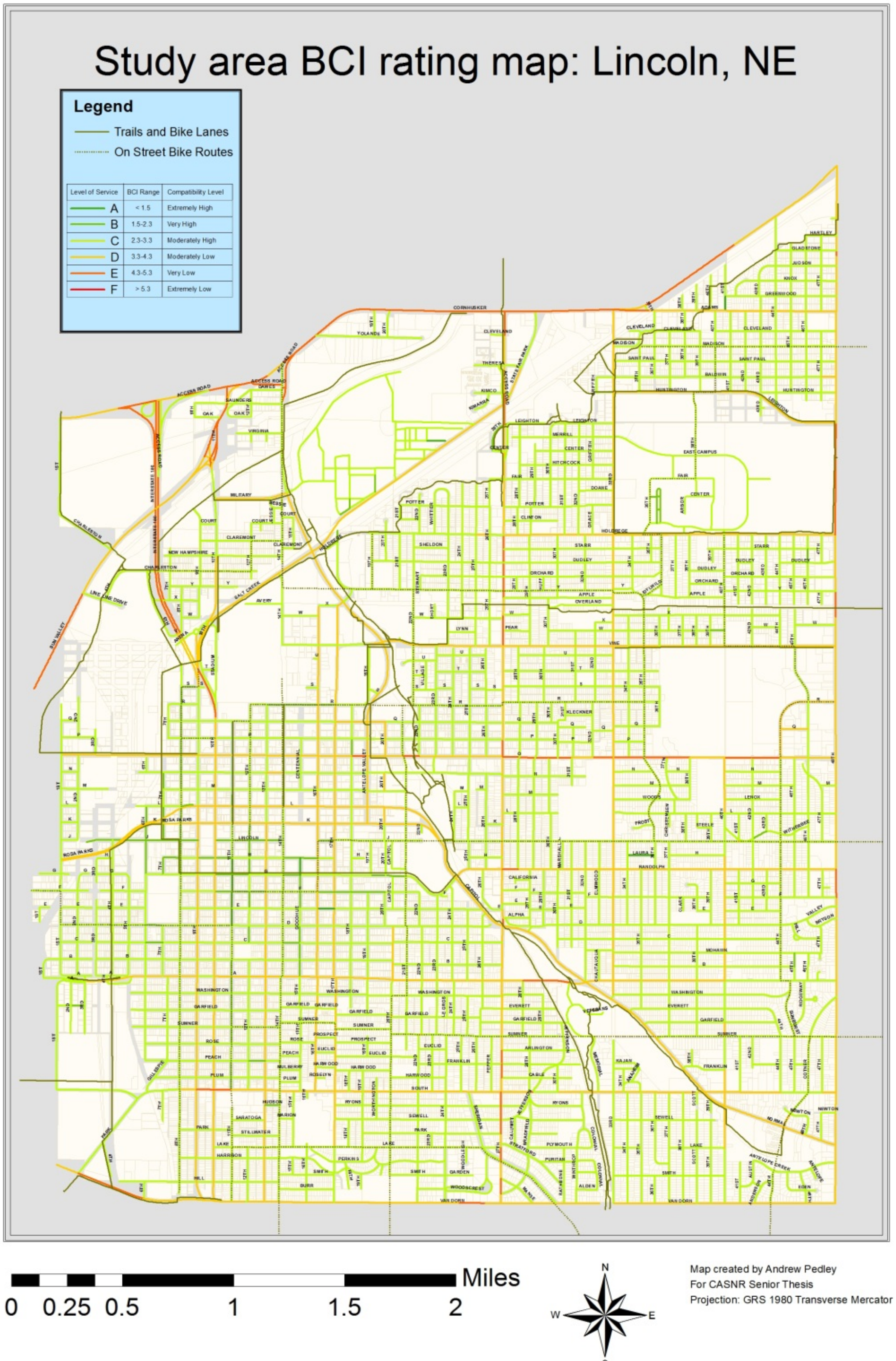
Rybarczyk, G., & Wu, C. (2010). Bicycle facility planningusing GIS and multi-criteria decision analysis. *Applied Geography*, 282-293.

Tilahun et al. (2007). Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. *Transportation Research Part A*, 287-301.

Wilkinson, B. (1998). Ideas in motion: It will take incentives and disincentives. *Transportation Quarterly, 52*(1), 12-13.

Winters, M., Brauer, M., Setton, E. M., & Teschke, K. (2010). Built environment influnces on healthy transportation choices: bicycling versus driving. *Journal of urban health:bulletin of the New York Acedemy of Medicine, 87*(6), 969-993.

Appendix A


Study area BCI rating map: Lincoln, NE
Legend
Trails and Bike Lanes
On Street Bike Routes
Level of Service
BCI Range
Compatibility Level
A
< 1.5
Extremely High
B
1.5-2.3
Very High
C
2.3-3.3
Moderately High
D
3.3-4.3
Moderately Low
E
4.3-5.3
Very Low
F
> 5.3
Extremely Low
0 0.25 0.5 1 1.5 2
Miles
N
S
W
E
Map created by Andrew Pedley
For CASNR Senior Thesis
Projection: GRS 1980 Transverse Mercator